# Automaton Rover for Extreme Environments (AREE)

Completed Technology Project (2016 - 2017)

## Project Introduction

Venus, with its sulfuric acid clouds, temperatures of over 450', and surface pressure of 92 bar, is one of the most hostile planetary environments in the solar system. Only a handful of Soviet Venera and Vega landers have successfully reached the surface of Venus. Even these robust probes only survived for 23 to 127 minutes before the electronics failed in the hostile environment. However, an entirely mechanical design, utilizing hardened metals could survive, collect, and return valuable long term longitudinal science data from the surface of Venus for weeks, if not months. This science data is critical for informing models of dynamic planetary systems. Automata are a centuries old concept. These unique devices are purely mechanical, self-operating machines capable of performing sequences of operations and instructions. Almost 2,300 years ago the ancient Greeks built the Antikythera automaton. This purely mechanical computer enabled accurate predictions of past and future astronomical events without utilizing any electronics. We propose a paradigm shift by replacing electronics with a fully mechanical systems design to enable exploration of the most extreme environments within the solar system. The specific mission context of Venus is explored in this proposal, but automata are applicable to other extreme environments in the solar system including Mercury, Jupiter's radiation belts, the interiors of gas giants, the mantle of the Earth and volcanoes throughout the solar system. AREE is unexplored as it offers a paradigm shift in spacecraft architecture, yet is still credible as automatons have operated on earth for centuries. It is exciting to think about how a new application of ancient technology could revolutionize the exploration of extreme environments, and allow mankind to unlock the secrets of Venus and other hostile environments across the solar system.

## Anticipated Benefits

Automata could be the key for unlocking the secrets for some of the most extreme environments in the solar system such as the surface of Venus. AREE, the Automaton Rover for Extreme Environments replaces vulnerable electronics with an entirely mechanical design. By utilizing high temperature alloys, the rover would survive for weeks if not months, allowing it to collect and return valuable long term longitudinal science data from the surface of Venus. This science data is critical for informing models of dynamic planetary systems.

An automaton rover combines ancient mechanical computers with modern manufacturing technology to create a design without electronics, enabling exploration of the most extreme environments in the solar system. Credits: Jet Propulsion...

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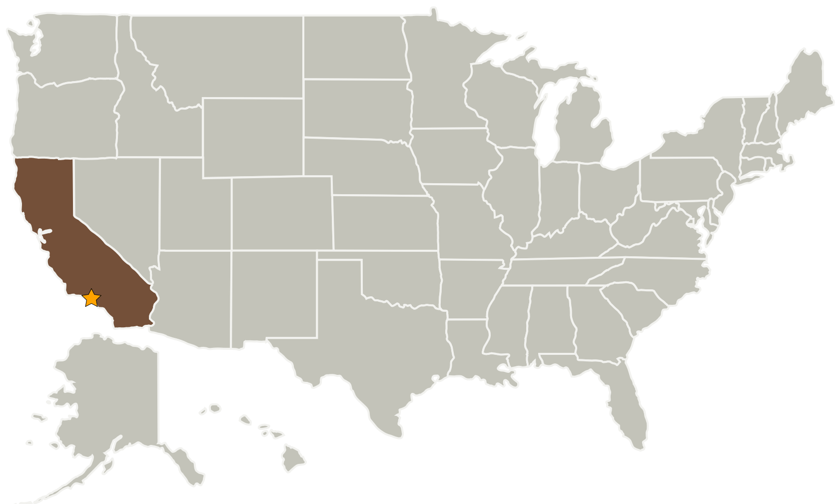
### Primary U.S. Work Locations and Key Partners



| Organizations Performing Work | Role | Type | Location |
|---|---|---|---|
| ★Jet Propulsion Laboratory(JPL) | Lead Organization | NASA Center | Pasadena, California |
| California Institute of Technology(CalTech) | Supporting Organization | Academia | Pasadena, California |

| Primary U.S. Work Locations |
|---|
| California |

### Project Transitions

**July 2016:** Project Start

## Organizational Responsibility

**Responsible Mission Directorate:**

Space Technology Mission Directorate (STMD)

**Lead Center / Facility:**

Jet Propulsion Laboratory (JPL)

**Responsible Program:**

NASA Innovative Advanced Concepts

## Project Management

**Program Director:**

Jason E Derleth

**Program Manager:**

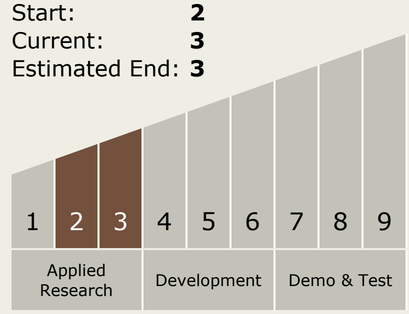
Eric A Eberly

**Principal Investigator:**

Jonathan F Sauder

## Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



**June 2017:** Closed out

**Closeout Summary:** Mechanical automata and computers have not been consi dered a serious avenue of scientific research since before early work on compute rs in the 1950s. Even then, much of the prior research into mechanical compute rs did not make it into the literature as it was related to the war effort and consi dered classified. The first phase of the project was to create a point design and exhaustively research the literature on the varied topics requiring greater refine ment. At every opportunity, subject matter experts were engaged to provide inp ut on the feasibility of various ideas and brainstorm for creative solutions to nov el problems. The Jet Propulsion Laboratory employs many individuals who specia lize in varied topics ranging from materials science, mechanism design, extreme environments, radar, science, spacecraft systems, and mission architectures, an d the names of those consulted are listed in the end of this report. The concept was showcased at forums within JPL, such as the Mechanical Systems Division S eminar, and external, including the Venus Exploration Analysis Group (VExAG), I EEE Aerospace Conference (paper submission), and AIAA SciTech (featured pres entation). This exposure allowed for the generation of additional ideas and know ledge of what has been done before and where there are holes in current capabil ities. Midway through the project an A-team Study (an early formulation team in the JPL Innovation Foundry) was used help to leverage the breadth and depth of experience at JPL and collate ideas and concerns from various disciplines. The st udy incorporated a presentation of the point design and shorts talks from releva nt experts in various relevant fields. Through discussion, the workshop narrowed down the primary science objectives (seismic and geologic), provided insight on the most robust architecture, and provided guidance on next steps. The final ph ase of the project involved comparing what we think could be done with an auto maton to the current state of the art in fields like high temperature electronics 2.2 Assessment Against Phase One Goals The goal of the Phase One study was t o generally determine the feasibility and value of using an automaton to explore Venus. Three main questions were brought forth in the original proposal and are repeated below along with an assessment of the Phase One finding. 1) Can an a utomaton explore and record data from the surface of a hostile world? A viable s ystems architecture was developed for the automaton rover, however, it is not p ractical to make a purely mechanical rover. High temperature electronics are inc orporated where they have sufficient maturity and application, such as instrume ntation. A system by system breakdown is provided in Section 4.0. 2) Can infor mation gathered be communicated to Earth? An in depth trade was performed t o determine the feasibility of getting information back to Earth and understand h ow to communicate science data using the limited resources. See Section 4.5. 3) What science questions can most effectively be answered with low bit rate co mmunication? Radar scientists and engineers at JPL were brought on to determi ne the value of low bit rate longitudinal science on Venus and the question was addressed as part of the workshop held on the automaton concept. Science retu rn is discussed in Section 3.0. 2.3 Key Findings The Phase 1 study showed that t here are no technological or physical barriers preventing an automaton rover wit hin the Venus context. The key areas investigated were computing elements, m ass and volume constraints from the EDL system, power generation, power stor age, communication link to Earth, science instruments, materials, and control, w hich are all discussed later in this document. The study also revealed that a fully mechanical rover, while feasible, is not practical. This conclusion resulted from a n A-team Study held to explore AREE in more detail combined with a review of h igh temperature electronic technologies. Fundamentally, building a mechanical c omputer with 1,000+ transistors would require a technology investment similar

## Technology Areas

**Primary:**

- TX08 Sensors and Instruments
  - └ TX08.3 In-Situ Instruments and Sensors
    - └ TX08.3.6 Extreme Environments Related to Critical System Health Management

## Target Destination

Others Inside the Solar System

## Images

**Project Image**
An automaton rover combines ancient mechanical computers with modern manufacturing technology to create a design without electronics, enabling exploration of the most extreme environments in the solar system. Credits: Jet Propulsion Laboratory/California Institute of Technology, background from ESA.
*(https://techport.nasa.gov/image/102268)*

## Links

NASA.gov Feature Article
*(https://www.nasa.gov/feature/automaton-rover-for-extreme-environments-aree)*